IN-FLIGHT MEASUREMENTS OF DYNAMIC FORCE AND COMPARISON WITH METHODS USED TO DERIVE FORCE LIMITS FOR GROUND VIBRATION TESTS

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ABSTRACT

In-flight measurements of the dynamic forces acting between an aerospace component and it's supporting structure have recently been obtained on the Advanced Composition Explorer (ACE) spacecraft. An improved vibration testing technique, in which the force applied to the test item by the shaker is limited to the interface force predicted in flight, has been developed and used in many NASA space programs [1-4]. Until recently there were no in-flight measurements of dynamic force to evaluate the methods of predicting the force limits being used in these tests. Comparison of the in-flight data and ground test data in this paper provides a validation of the methods currently being used for predicting the force limits.

INTRODUCTION

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The flight data discussed in this paper were measured on the Advanced Composition Explorer (ACE) spacecraft, which was launched on August 25, 1997 to the L1 point between the earth and the sun. The ACE spacecraft carries eight scientific instruments to sample matter that comes near the Earth from the Sun. The ACE project was managed by NASA Goddard Space Flight Center, the spacecraft was built by the Applied Physics Laboratory, and the instruments were managed by the California Institute of Technology. The spacecraft instrumentation includes a Spacecraft Launch Acceleration Measurement (SLAM) data acquisition system to measure, record, and transmit dynamic data at launch of the spacecraft on the Delta II launch vehicle. The SLAM instrumentation includes a channel for the high-frequency (20 to 2000 Hz) acceleration measured normal to the spacecraft honeycomb panel near one of the twelve mounting feet of the Cosmic Ray Isotope Spectrometer (CRIS) instrument and also a channel for the total normal force measured under the twelve mounting feet of the CRIS instrument. The Delta II 7920-8 launch vehicle has two stages and nine solid boosters. The Delta II ~~eight 2 ft.~~ (2.5m) (8-ft)- diameter aluminum fairing has a standard 38-mm (1.5-in.) ~~(38 mm)~~ thick acoustic blanket.

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A second flight project, The Shuttle Vibration Forces (SVF) experiment, designed to measure the dynamic forces acting between the space shuttle and a Get-Away-Special (GAS) canister attached to the shuttle sidewall, has yet to produce useful flight data. In the first SVF flight, STS-90 in April 1998, two of the three tape recorders (including the one with the force data) failed. A second SVF flight, STS-96, is planned for May 1999.

GROUND VIBRATION TEST

Figure 1 shows the CRIS instrument mounted on the side of the ACE spacecraft bus, which is a two-deck octagon honeycomb structure, ~~65 in. (1.6m)~~ across and (40 in.) (1m) high. Figure 2 shows the CRIS instrument mounted on the shaker ready for the vertical axis vibration test. The CRIS instrument weighs approximately 65 lb. (30 kg) and is mounted on 12 piezoelectric force gages both for the vibration test and for flight. In the test, tri-axial force gages are utilized, and in flight, uni-axial gages are used to measure the force normal to the honeycomb panels. In both cases, the outputs of the 12 transducers are summed in real time to produce the total force, in each axis.

1.6 m (65 (typ

Figure 3 shows tap test data in the form of a frequency response function, which is the ratio of applied force to response acceleration. The data were measured on a honeycomb panel of the ACE spacecraft bus, at one of the 12 CRIS mounting points. Figure 4 shows the sine sweep force data measured in a 0.25 G acceleration input vibration test of CRIS instrument.

Figure 5 presents results from the simple two-degree-of-freedom (TDFS) method for developing force limits [2], which method requires the ratio of load to source effective masses. The panel tap test data in Figure 3 must be multiplied by a factor of $12^{0.5}$, to account approximately for the twelve mounting points, and the CRIS data sine sweep test data in Figure 4 must be multiplied by a factor of four to account for the 0.25 G input and by a second factor of 1.2 to account for the shunt force in the force gage bolt. With these adjustments, the effective masses of the ACE panel and the CRIS instrument are comparable at frequencies above the fundamental resonance of the CRIS instrument in the vertical vibration test, which resonance is just below 200 Hz.

The force limit for the CRIS instrument is predicted using the semi-empirical method [3,4] given by Eq. 1.

$$
\begin{aligned}
S_{FF}(f) &= C^2 M^2 S_{AA}(f) & f < f_o \\
&= C^2 M^2 S_{AA}(f)\,[\,(f_o / f)^2], & f > f_o
\end{aligned}
\qquad (1)
$$

where: $S_{FF}(f)$ is the force specification spectral density, C is a constant chosen by user, M is the <u>total</u> mass of test object, $S_{AA}(f)$ is the acceleration specification spectral density, and f_o is the fundamental frequency on the shaker. For the CRIS instrument, the constant, which is the value of the ordinate of Figure 5 for an M_2/M_1 value of 1.7.

Figure 6 shows the total vertical force in the CRIS random vibration test, and Figure 7 shows the notched acceleration input. The force in Figure 6 has been limited to 800 lbs^2/Hz, which is the value given by Eq. 1. with C^2 equal to 2. Notice from Figure 7, that the maximum value of the acceleration specification for the CRIS instruments is 0.16 G^2/Hz.

FLIGHT DATA

Figure 8 shows the spectral density of in-flight normal acceleration measured near one mounting foot of the CRIS instrument. Notice that the maximum flight acceleration spectral density is 0.001 G^2/Hz, which is two orders-of-magnitude lower than the instrument random vibration test specification in Figure 7. Figure 9 shows the spectral density of in-flight normal force measured under CRIS instrument. Both of these spectra were computed for a time history of one-second duration during the lift-off event, at which time both the force and acceleration reached their maximum values. Notice from Figures 8 and 9 that both the interface force and acceleration peak at the same frequencies, which is a fundamental assumption of both the simple and the complex TDFS methods of computing force limits [2]. The force spectra decreases with frequency, above the major resonance. The coupled system resonance frequencies are approximately 33 Hz and 135 Hz, which are different ~~than~~ from the fundamental resonance, just below 200 Hz, which is exhibited in the sine sweep vibration test data in Figure 4. As expected from the dynamic absorber effect, the flight interface acceleration data show a notch just below 200 Hz.

Figure 10 shows the ratio of the flight force spectral data to the flight acceleration spectral data. The ratio of the force to the acceleration spectra at the flight data resonance frequencies of 33 Hz and 135 Hz are approximately 1,000 lbs^2 and 5000 lbs^2, respectively. The higher value of the ratio at 135 Hz agrees with the semi-empirical method with a constant C^2 of 2.

CONCLUSIONS

The SLAM flight measurement system on the ACE spacecraft performed flawlessly. The acceleration input spectral levels specified for the random vibration tests of the instruments on the ACE spacecraft were approximately 20 dB higher than the flight data measured near three of the instruments. The CRIS instrument flight acceleration and force data both peak at 33 Hz and 135 Hz, compared to a peak just below 200 Hz on the shaker. The flight force measurement agrees with the force limit calculated using the simple TDFS and semi-empirical force prediction methods.

ACKNOWLEDGMENTS

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REFERENCES

1. T. Scharton, "Force Limits for Vibration Tests", Spacecraft Structures and Mechanical Testing Conference, Paris, June 1994.

2. Scharton, ~~T. D.~~, "Vibration-Test Force Limits Derived From Frequency-Shift Method", AIAA Journal of Spacecraft and Rockets 32(2), 1995, pp. 312– 316.

3. K. Chang and T. Scharton, "Verification of Force and Acceleration Specifications for Random Vibration Tests of Cassini Spacecraft Equipment", Proc. of ESA Conference on Spacecraft Structures, Materials & Mechanical Testing, Netherlands, 27-29 March, 1966.

4. T. Scharton, "Monograph on Force Limited Vibration Testing", NASA RP-1403, May 1997.

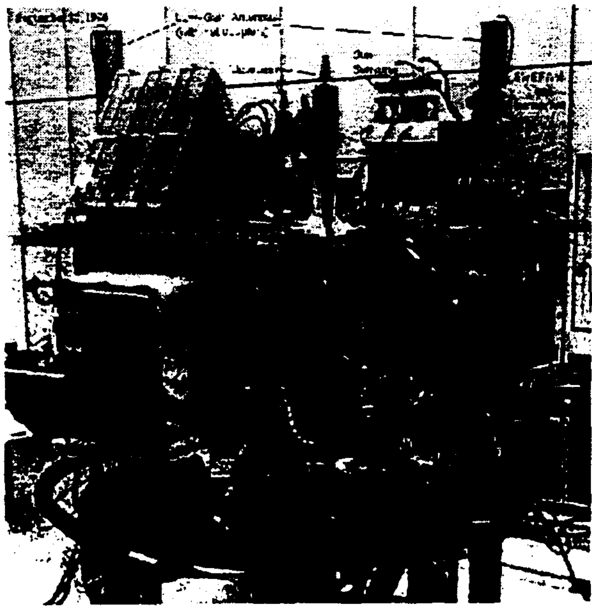


FIGURE 1. CRIS INSTRUMENT ON ACE SPACECRAFT BUS

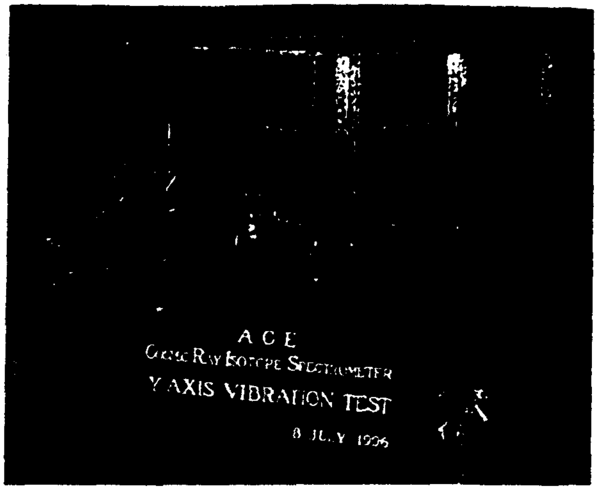


FIGURE 2. CRIS INSTRUMENT ON SHAKER

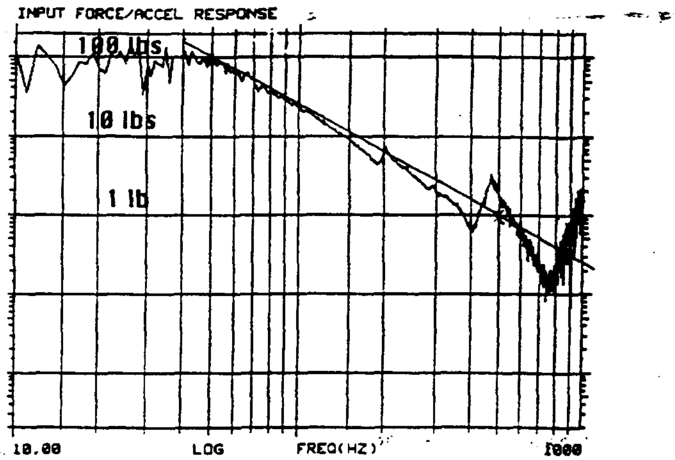


FIGURE 3. TAP DATA FROM ACE SPACECRAFT PANEL AT CRIS

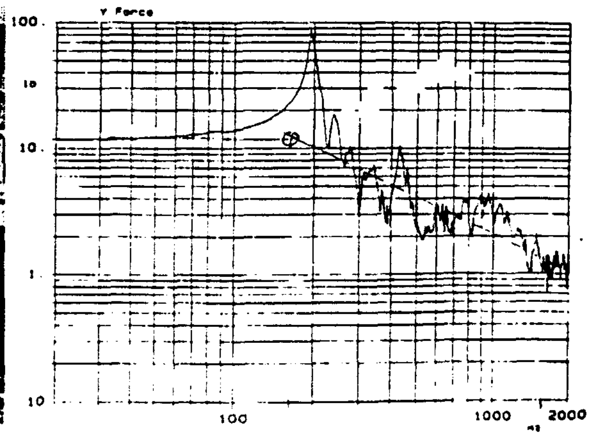


FIGURE 4. CRIS SINE SWEP DATA FROM 0.2 G INPUT VIBRATION TEST

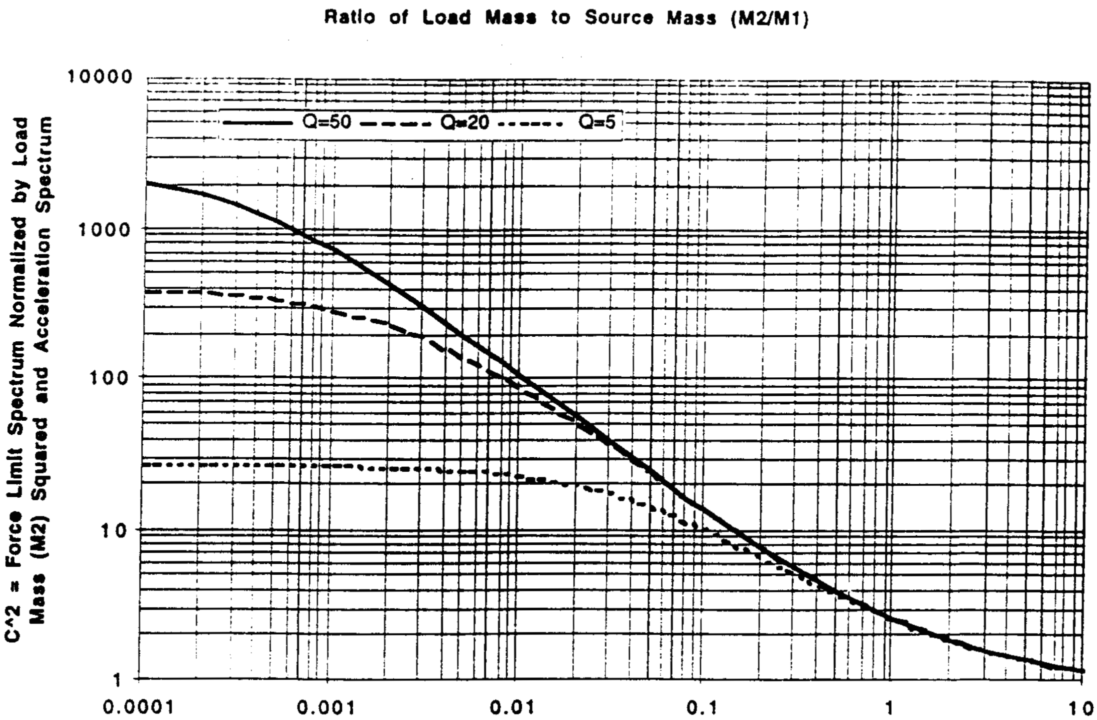


FIGURE 5. SIMPLE TDFS METHOD FOR DEVELOPING FORCE LIMITS

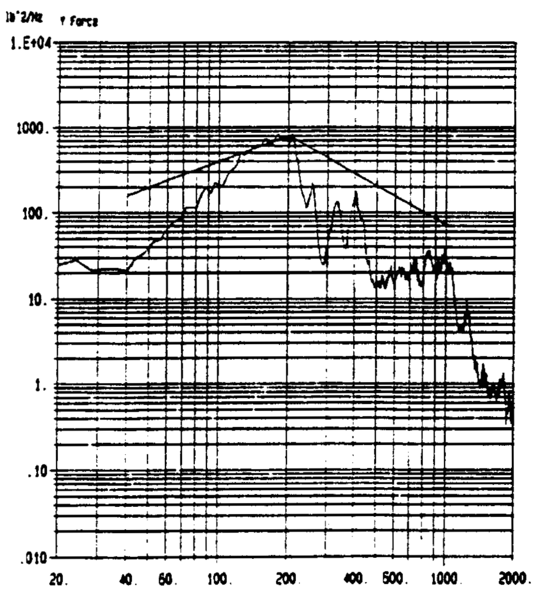


FIGURE 6.TOTAL VERTICAL FORCE IN CRIS RANDOM VIBRATION TEST

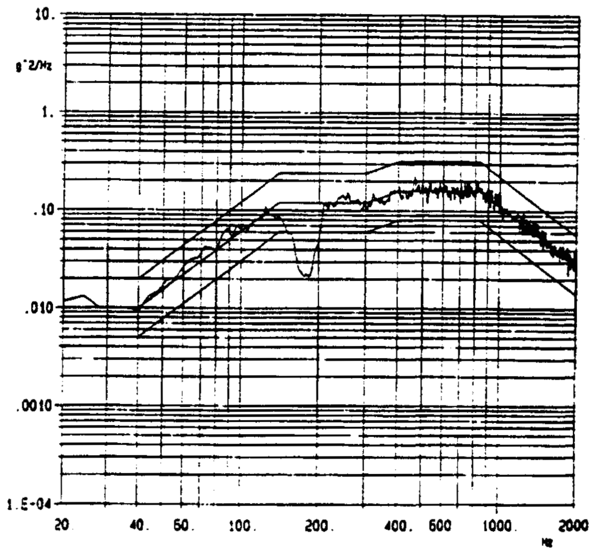


FIGURE 7. NOTCHED ACCELERATION INPUT IN CRIS RANDOM VIBRATION TEST

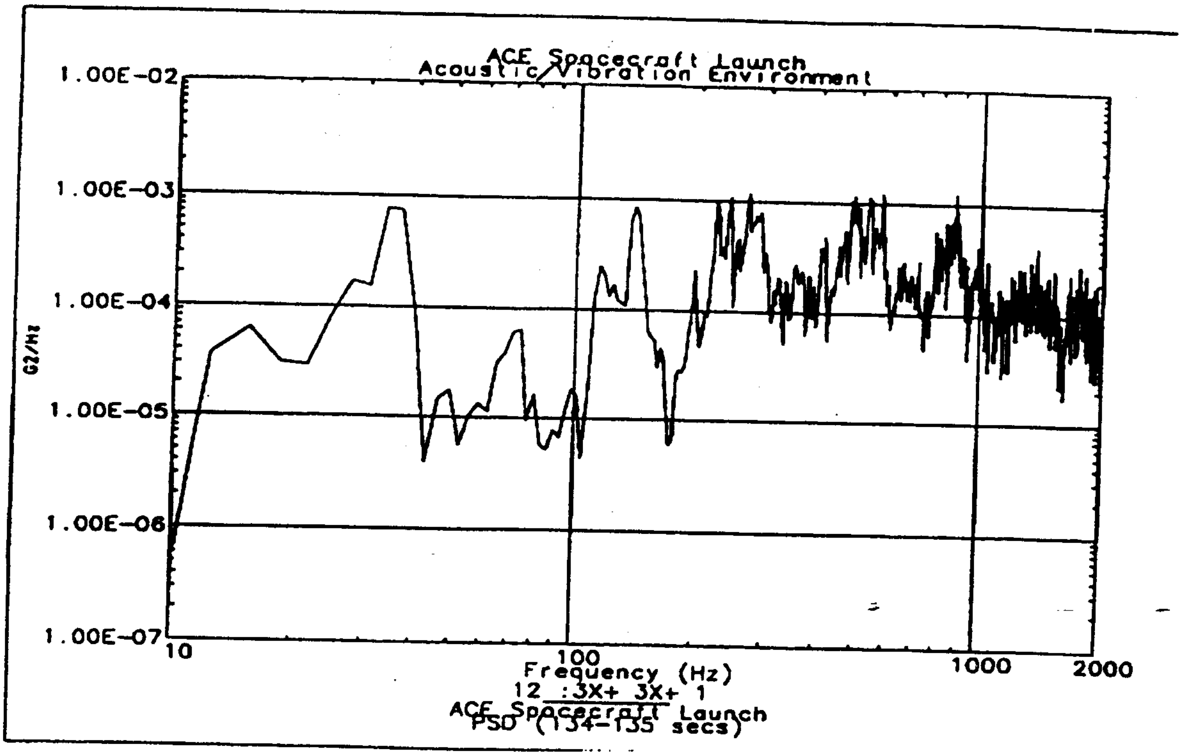


FIGURE 8. SPECTRAL DENSITY OF IN-FLIGHT NORMAL ACCELERATION MEASURED NEAR ONE MOUNTING FOOT OF CRIS INSTRUMENT

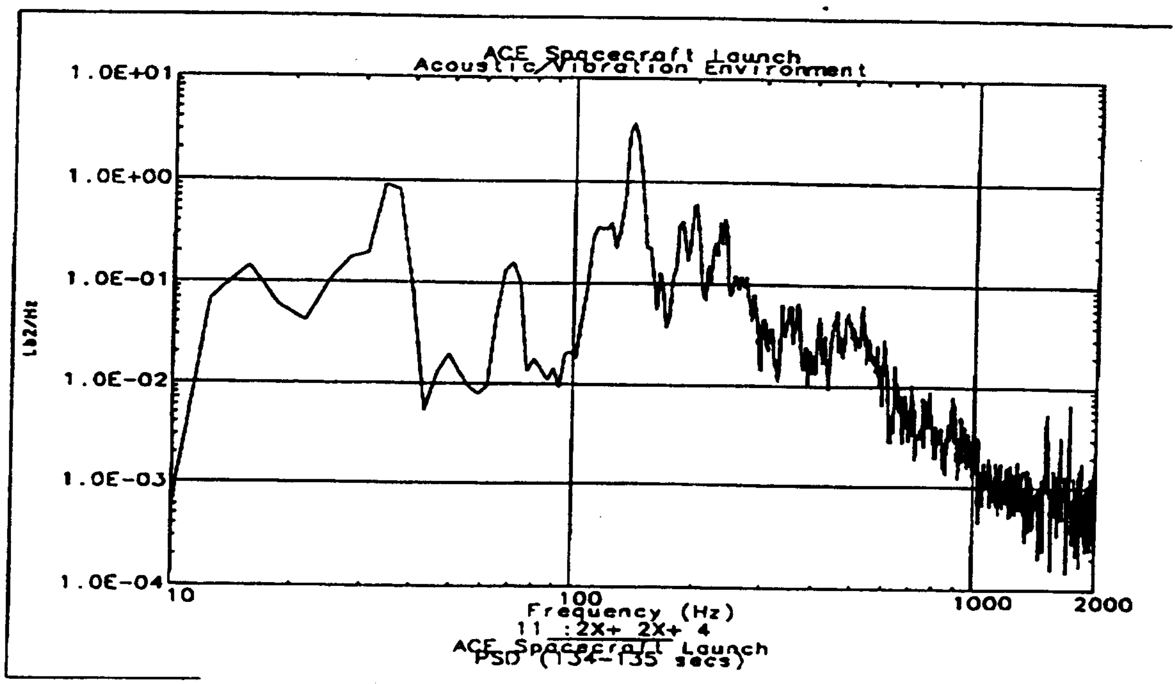
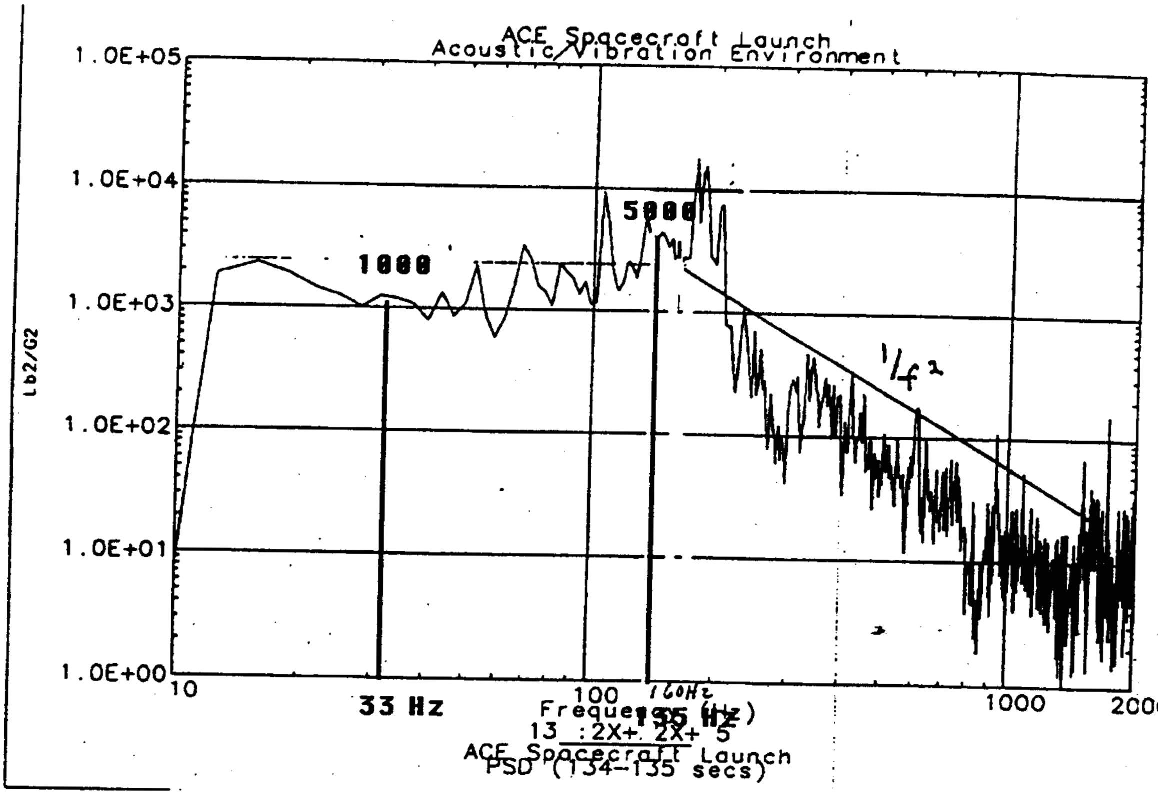


FIGURE 9. SPECTRAL DENSITY OF IN-FLIGHT NORMAL FORCE MEASURED UNDER CRIS INSTRUMENT



10. RATIO OF CRIS IN-FLIGHT FORCE TO ACCELERATION SPECTRAL DENSITIES